

Fatigue life prediction of welded stiffened 350WT steel plates

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Abstract

The propagation of fatigue cracks under constant amplitude cyclic loading was studied in welded stiffened steel plates. The residual stresses in the stiffened plates were measured using the neutron diffraction strain-scanning technique. A finite element model of the stiffened plate was constructed to simulate the residual stresses by an uncoupled thermal and thermo-mechanical analysis. Both the finite element model and the neutron diffraction measurements indicated that in general the residual stresses were tensile near the welded stiffeners and compressive between the stiffeners and ahead of the starter notch tip. Fatigue testing indicated that the fatigue crack growth rates of the stiffened plates were in general lower than that of a corresponding unstiffened plate, especially near the notch tip where compressive residual stresses existed. Both the finite element method and Green's function predicted the fatigue crack growth rates with reasonable accuracy.

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1. Introduction

Typical stiffened sheet structures are metal sheets reinforced by stiffeners and are widely used in aircraft, ships and chemical industry structures for their light weight and high

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strength and stiffness. They are mostly found in the airframes, fuselages and wings of aircraft and the deck and side plating on a ship where the amount of fatigue loading is the greatest. Much research has been performed in the past to address fatigue crack growth in aircraft, with the studies made on aluminium panels that have either riveted or adhesive bonded stiffeners. On the other hand, relatively few studies [1–7] have been conducted on welded stiffeners that are often found in ship structures. This type of stiffeners induces complex residual stresses in the structure that are caused by the heating and cooling effects of welding. In general, the fatigue behaviour of welded stiffeners is not well understood and test data of this type are scarce. Nonetheless, the distribution of these residual stresses is recognized to have considerable influence on the fatigue crack growth rates of welded stiffened panel.

In the present investigation, the fatigue behaviour of welded stiffened centre-cracked 350WT steel plates was studied. The residual stress fields near the fatigue crack tips in the steel plates were evaluated using the neutron diffraction method, which is a versatile and nondestructive technique [8–28]. The steel plates then underwent fatigue testing. The residual stress fields were also simulated by the finite element method. The effective stress intensity factors produced by the residual stress fields were then calculated by two methods: by Green's function and by fracture mechanics analysis. Finally, the fatigue crack growth rates of the stiffened plates were predicted using the effective stress intensity factors and compared to the experimental results.

2. Background

2.1. *Fracture mechanics of stiffened sheet structures*

From a static loading point of view, stiffened structures provide higher buckling strength and flexural stiffness. In terms of fracture mechanics, stiffeners provide a secondary structure for the load to bypass a cracked panel. The crack tip stress intensity factor is therefore lowered in the vicinity of a stiffener so that the growth of a crack towards a stiffener is slowed down or even arrested.

In the case of a mechanically fastened stiffener, a crack progressing in the base plate will not propagate up into the stiffener. This presents the beneficial effect of load shedding, as the load originally placed on both the base plate and the stiffeners is transferred to the intact stiffeners. In such a case, the crack may only grow to a limited length because the intact stiffeners constrain the crack opening displacement, thereby decreasing the driving force of the crack.

On the other hand, in case of welded stiffeners, there is no real crack arrest, but only a reduction of crack growth rate. In addition, the crack can grow into the stiffener and thereby severing it. The stiffener then loses its efficiency and its load is shed to the remaining net section of the base plate, causing a jump in the stress intensity factor. Furthermore, the welded sites are also prone to contain regions of poor microstructure and defects. They are therefore frequently a source where fatigue cracks initiate. Finally, as mentioned before, fatigue life of welded stiffened structures are significantly affected by the welding residual stresses.

Nevertheless, a stiffened structure can sustain cracks more safely and cracks can grow in a more stable manner until the structure is repaired or its economic service life has expired.

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